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published in
European Journal of Applied Physiology
1992

DOI (link to publisher)
10.1007/bf00636214

document version
Publisher's PDF, also known as Version of record

Eur J Appl Physiol (1992) 64:292-297

European Journal of Applied Physiology and Occupational Physiology

Supramaximal cycle tests do not detect seasonal progression in performance in groups of elite speed skaters

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Accepted November 27, 1991

Summary. Seven female and eight male elite junior skaters performed cycle ergometer tests at four different times during the 1987/1988 season. The tests consisted of a Wingate-type 30-s sprint test and a 2.5-min supramaximal test. The subjects were tested in February, May and September 1987 and in January 1988. Maximal oxygen consumption was measured during the 2.5-min test. With the exception of the maximal oxygen consumption of the women in May which was about 6% lower than in the other three tests, no seasonal changes in the test results could be observed - this, in spite of a distinct increase in training volume (from 10 to more than 20 $h \cdot week^{-1}$) and training intensity in the course of the season. When the test data were compared to those of elite senior skaters, it appeared that the junior skaters showed the same values for mean power output during the sprint test [14.2 (SD 0.4) $W \cdot kg^{-1}$ for the men and 12.6 (SD 0.5) $W \cdot kg^{-1}$ for the women] and maximal oxygen consumption [63.1 (SD 2.8) $ml \cdot kg^{-1} \cdot min^{-1}$ for the men and 55.3 (SD 3.5) $ml \cdot kg^{-1} \cdot min^{-1}$ for the women, respectively] as found for senior skaters. It seemed, therefore, that the effects of training in these skaters had already levelled off in the period before they participated in this investigation. In contrast to previous studies, no relationship could be shown between the test results and skating performance. This was most likely due to the homogenous character of the groups (mean standard deviations in power and oxygen consumption were only 5%). It was concluded that the present cycle tests used to measure aerobic and anaerobic power were obviously not of use in evaluating seasonal changes in performance in these groups of highly trained athletes.

Key words: Aerobic power - Anaerobic power - Training

Offprint requests to: G. J. van Ingen Schenau

Introduction

One of the aims in the conditioning of endurance athletes is to improve their maximal aerobic and anaerobic power because a high total power production is an important prerequisite for success. When compared to other endurance athletes, elite speed skaters appear to have had a moderately high aerobic power of 60–70 $ml \cdot kg^{-1} \cdot min^{-1}$ for the men and 50–60 $ml \cdot kg^{-1} \cdot min^{-1}$ for the women (Ekblom et al. 1967; Maksud et al. 1970; Ingen Schenau et al. 1983, 1988; Nemoto et al. 1988; Foster et al. 1990). Their anaerobic power output as measured during 30-s supramaximal cycling has belonged to the highest recorded by any group of athletes (up to mean power outputs of 14 $W \cdot kg^{-1}$ for men and 12 $W \cdot kg^{-1}$ for women; Ingen Schenau et al. 1988; Foster et al. 1990). This has reflected the observation that all-round speed skating performances rely heavily on the anaerobic pathways (Foster et al. 1990; Ingen Schenau et al. 1990; Koning 1991). It has been shown that both the aerobic power as well as the anaerobic power can be judged as predictors of performance in speed skating (Geijsel et al. 1984; Foster et al. 1990).

Since an important part of the training of speed skaters is aimed at improving their maximal aerobic and anaerobic power, coaches are extremely interested in tests which can help to evaluate their training programmes in this respect. Due to the lack of ice in the season when training occurs on dry land (from March until October in most countries) sport scientists and sports medical centres mostly use cycle ergometer tests for these evaluations. Together with the 30-s Wingate-type of test (van Ingen Schenau et al. 1988) to obtain a measure for anaerobic power, we have applied a 2.5-min cycle test to measure maximal oxygen uptake ($\dot{V}O_{2\,max}$; and total power output) during supramaximal exercise because five out of the six metric-style skating events in all-round speed skating also involve exercise with an intensity above 100% $\dot{V}O_{2\,max}$ (Geijsel et al. 1984; Ingen Schenau et al. 1988). During the past 6 years these two tests have been used to evaluate the physical condition of those selected to represent Dutch junior speed skaters. The most complete set of data was collected in the season between January 1987 and January 1988 when all members (seven women and eight men) were tested at four different times throughout the year. The purpose of this study was to show the seasonal changes in aerobic and anaerobic power of these skaters as reflected in these test results to establish the usefulness of this type of testing in the evaluation of the training of these homogenous groups of highly trained athletes.

Methods

Subjects. The subjects were among those selected by the Dutch Skating Association to represent Dutch junior speed skaters on the basis of their performances in national and international competitions. In the 1987-1988 season the selection consisted of eight men and seven women, all in the age range of 16-19 years. Body mass, percentage of fat and range of best times at 500 m and 1500 m, are presented in Table 1. The percentage of fat was calculated from four skinfold measurements. The subjects were familiar with the tests since all had participated in at least one of the test sessions in the previous season.

Training. Following the last skating competitions of the previous season training was interrupted between the second half of March and the beginning of May. From May until October the subjects trained on land since during this period skating rinks are closed in Holland. During this period of training on dry land as well during the following one on ice, the subjects trained in the one-competition-period principle based on 3-week macro cycles (Kloosterboer

Table 1. Body mass, percentage of fat and the best seasonal times at the 500 m and 1500 m

	mass (kg)		% Fat		500 m (s)	1500 m (min sec)
	mean	SD	mean	SD	range	range
Women ($n=7$)	59.5	6.2	20.1	1.8	42.1-44.7	2: 11.5-2 22.0
Men ($n=8$)	77.1	6.6	9.9	1.2	39.1-41.1	1: 56.3-2 03.2

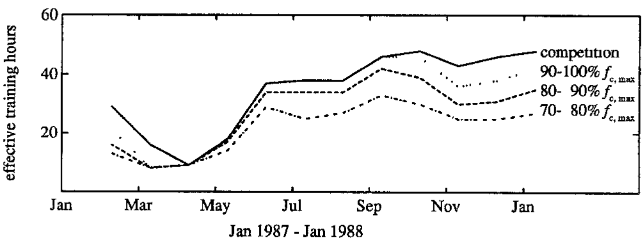

Fig. 1. An outline of the number of (effective) training hours per month spent in three types of training at different levels of intensity and in competitions in the course of the training season 1987/1988. The percentages of maximum cardiac frequency ($\%f_{c,max}$) indicate the number of hours that mean cardiac frequency during that type of training lay within that range of $f_{c,max}$. The hours spent in competitions have been estimated by assuming that each day of participation in competitions represented 1.5 h of training. Hours spent in strength training, warming up, cooling down and stretching have not been included

1987). The number of training hours was increased during the season. Together with this increase in total volume, there was a gradual increase in the proportion of high intensity training during the season. Figure 1 shows how training overall was subdivided into exercises at three different intensities, i.e.

1. Endurance training: various exercises which could be sustained for long periods at mean cardiac frequencies of about 70-80% of maximal cardiac frequency ($f_{c,max}$) which has been shown to correspond to an intensity at which no more than about 4 mmol$\cdot$l^{-1} lactate is accumulated in the blood (e.g. Kloosterboer 1987; Foster et al. 1990).
2. Intensive endurance and extensive interval training: various training exercises at (mean) cardiac frequencies of 80%-90% of the $f_{c,max}$.
3. Intensive interval and tempo-training: various training exercises with mean cardiac frequencies of 90%-100% of $f_{c,max}$ leading to blood lactate concentrations of 15-20 mmol$\cdot$l^{-1} (Foster et al. 1990).

These exercises in the main included cycling, running, roller skating and, from October on, ice skating. Note that Fig. 1 presents the mean number of training hours in an accumulative way. The upper curve thus presents the total number of hours per month spent on different training exercises at the intensity levels indicated. Only effective training time is indicated. To calculate the total number of hours spent in training, these numbers should be multiplied by 1.5 to account for warming up, cooling down and stretching exercises. The number of hours spent in competitions was estimated by assuming that during a day of competition (normally including two distances) the subjects spent 1.5 h in training. The strength training is not included in Fig. 1. From June until September the volume of the strength training varied between 7 and 9 (effective) h$\cdot$month^{-1} while during the competitive season (December-March) this volume was gradually decreased from 4 h in December to no strength training in March. Between May and January the weights used in strength training were gradually increased from 40%-60% of one repetition maximum (RM) in May to 70%-90% RM from November until January. Including warming up, etc. the total volume of training was approximately 65 h in June and this increased to about 80 h in the period between September and February. In Fig. 1 a distinct build up of training during the season can be seen. (For details of the comparable training build up in senior skaters, see Gemser and Ingen Schenau 1987.)

The tests. The 30-s sprint test and the supramaximal 2.5-min test were performed on an electrically-braked cycle ergometer (Mijnhardt). All subjects were tested in the 2nd week of February, the 1st week of May, the last week of September (1987) and in the 2nd week of January 1988. Since the test results were used by their coach, the subjects were highly motivated to participate. The protocols used in the two tests have been described in detail previously (Ingen Schenau et al. 1988) and are summarized here.

The 30-s sprint test was a Wingate-type test in which the subjects had to perform all-out right from the start. This resulted in a peak power output (P_{peak}) at about 5 s after the start, followed by a marked decrease in power output (P) thereafter. Mean power output ($\bar{P}$) was calculated from the area under the power-time curve. The sprint test was preceded by a warm-up, which consisted of submaximal cycling (100 W) interrupted by short lasting bursts of high intensity. After this warm-up, the subjects took a 2-min rest before the actual test. Following this sprint test and a 5-10 min cooling down period of cycling at 100-150 W, the subjects rested for at least 45 min before the supramaximal 2.5-min test was performed.

The warm-up for the 2.5-min test consisted of 3-min cycling at 100 W and 3-min cycling at 180 W. There was no rest period between these submaximal warm-up periods and the 2.5-min period of supramaximal cycling. Mean power output over 2.5 min ($\bar{P}_{2.5}$) was calculated from the instantaneous power-time curve, and $\dot{V}O_{2max}$ was measured every 30 s during the 2.5 min using an Oxycon 4 (Mijnhardt) gas analyser. The gas analyser was calibrated prior to each test.

As has been indicated before (Ingen Schenau et al. 1988), the initial setting of the brake force is crucial in these types of supramaximal tests of fixed duration. Since all subjects had been tested before, the brake force setting for each individual could be determined from their previous test performances. This method appeared to minimize the risk of the brake force having to be adjusted during the race and resulted in pedal frequencies varying between 90 and 110 rpm.

In a previous study, it was shown that speed skating velocity depended on power output per kilogram body mass (Ingen Schenau and de Groot 1983b). Therefore P and $\dot{V}O_{2\,max}$ were expressed relative to body mass.

Results

The P_{peak} and $\overline{P}$ measured during the sprint test is shown in Fig. 2. The small standard deviations (mean 4.8%) of the results of both the male and the female group show that both can be regarded as homogenous. During the season no changes in these test results were observed.

Figure 3 shows $\dot{V}O_{2\,max}$ and $\overline{P}_{2.5}$ as a function of time. Again no changes during the season were observed with the exception of $\dot{V}O_{2\,max}$ of the women measured in May which was significantly lower (about 6%, $P < 0.05$) than the values measured at the end of the previous season (January 1987) and those measured later (September 1987 and January 1988). However, this lower $\dot{V}O_{2\,max}$ was not reflected by the total power during this test. The power remained the same throughout the season. In these results the standard deviations were of an order of magnitude of 8% or less (mean 5%). Together with the data given in Figs. 2 and 3, we also measured the respiratory exchange ratio, the $f_{c,max}$ and the ratio between ventilation and oxygen consumption during the 2.5-min test but none of these differed significantly among the four test sessions.

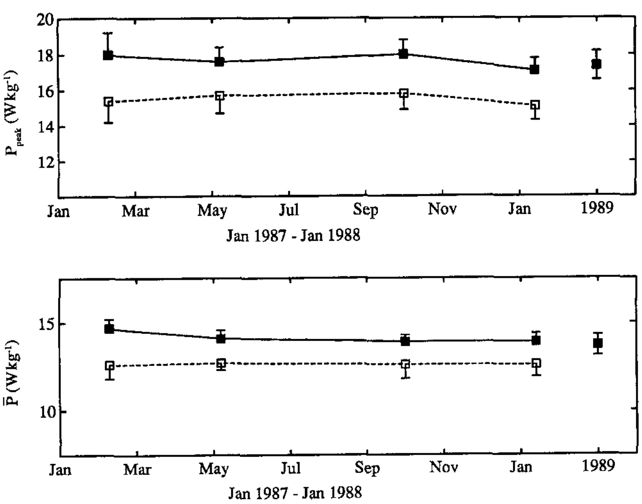

Fig. 2. Mean values and standard deviations of peak power (P_{peak}) and mean power ($\overline{P}$) during the 30-s sprint test for men (*filled symbols*) and women (*open symbols*) during the 1987/1988 season and mean values for the men 2 years later (*separate points*). No significant changes were observed

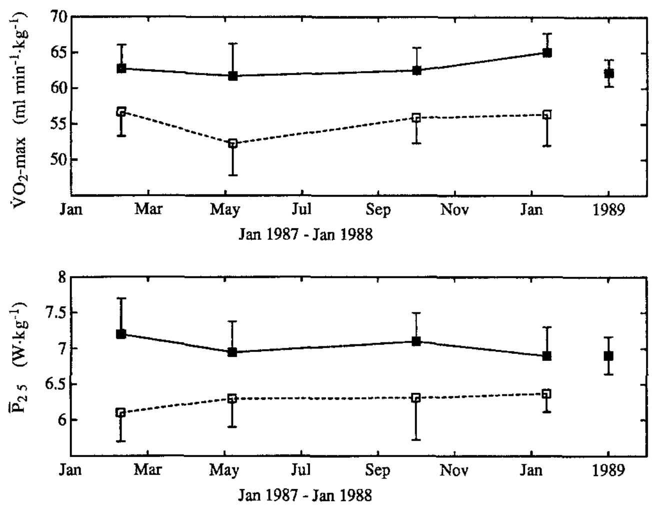

Fig. 3. Mean values and standard deviations of mean power output ($\overline{P}_{2.5}$) and maximal oxygen consumption ($\dot{V}O_{2\,max}$) of the men (*filled symbols*) and women (*open symbols*) measured during the 2.5 min tests. The *separate points to the right* are the mean values for the same men measured 2 years later
The $\dot{V}O_{2\,max}$ of the women measured in May was significantly lower than that measured in the other periods. No other significant changes were found

Discussion

The main result of this study was that these groups of highly trained athletes showed remarkably few changes in maximal anaerobic and aerobic power during the season in spite of a carefully chosen build-up in the training. In the first part of the season (May–September) the training was mainly focused on the improvement of the aerobic power while the accent was gradually shifted towards the improvement of anaerobic power. So the complete absence of any change in the 30-s test results was particularly striking. Since approximately 90% of the $\overline{P}$ in this test was liberated anaerobically [as can be deduced from the kinetics of the aerobic and anaerobic pathways presented by Ingen Schenau et al. (1990) and Koning (1991)], these results showed that anaerobic power was obviously not influenced by the changes in training intensity during the season. The slight increase in oxygen consumption in the women (and the comparable tendency observed in the men) between May 1987 and January 1988 might point to a relatively fast adaptation of aerobic power to the increasing training volume and intensity. This however was not reflected by the total $\overline{P}_{2.5}$ despite the fact that approximately 60% of the total work during this test depended on aerobic pathways. It was not clear why the men did not show a significant decrease in $\dot{V}O_{2\,max}$ after the period of reduced training. Possibly they reduced their exercises to a lesser extent than the women.

Comparable studies of seasonal changes in highly trained athletes are relatively few. Foster et al. (1990) have reported results for American speed skaters. In a comparison of power in the Wingate-test and $\dot{V}O_{2\,max}$ values measured in May with those measured in Sep-

Table 2. Mean results from (eight) male skaters collected in the season 1987/1988 compared to the results 2 years later (season 1989/1990)

	Mass (kg)	% Fat	P_{peak} ($W \cdot kg^{-1}$)	$\bar{P}$ ($W \cdot kg^{-1}$)	$\bar{P}_{2.5}$ ($W \cdot kg^{-1}$)	$\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	RER	$\dot{V}_E : \dot{V}O_2$	$f_{c,max}$ ($beats \cdot min^{-1}$)
1987/1988	77.1	9.9	17.7	14.2	7.0	63.1	1.31	31.5	189
SD	6.6	1.2	0.6	0.4	0.4	2.8	0.03	2.5	4
1989/1990	80.9	9.9	17.4	13.7	6.9	62.2	1.26	31.7	188
SD	4.9	1.6	0.8	0.6	0.3	1.9	0.07	1.5	5

P_{peak}, Peak power output; $\bar{P}$, mean power output; $\bar{P}_{2.5}$, mean power output over 2.5 min; $\dot{V}O_2$, maximal oxygen consumption; RER, respiratory exchange ratio; $\dot{V}_E : \dot{V}O_2$, ventilatory equivalent; $f_{c,max}$, maximal heart rate

tember, they also found no change. Gullstrand and Holmer (1983) have tested elite swimmers using swimming tests. In $\dot{V}O_{2max}$ they found no changes during the season but in swimming force (measured during tethered swimming) and maximal blood lactate accumulation they found (inversely related) changes during the season. The lowest lactate values and the highest forces were found during periods of competition. Dickhuth et al. (1988) have followed the physical condition of 11 middle distance runners during 8 months of training. They found fewer changes and considered that most of the effects of training had already been achieved in the first 3 weeks of training. Such an explanation, however, would seem to contradict the phenomenon often observed in practice that skaters who have reduced the volume of endurance training during the dry land period appear to become short of power during the longer skating distances 6 months later. However, the observation that those skaters appear in the main to have been able to maintain their performance level over the shorter distances might point to a relatively slow adaptation of maximal anaerobic power with training.

It would, therefore, be interesting to follow the skaters of this study over more than 1 year. With respect to the men this was possible since all eight men continued their training and participated in tests at least once in the years between 1988 and 1990. Six of the eight subjects were tested in November 1989. From one subject only a test at the beginning of 1989 was available and from another subject we took the average value of two tests, one taken in November 1990 and one in April 1988 assuming that the average would reflect his physical condition in 1989. For the women such a comparison was not possible since not all the subjects were still training in 1989. The mean values of the men in 1989 have been added as separate points to the curves of Figs. 2 and 3 and in Table 2 these and a number of other parameters are compared to the corresponding mean values of the four tests measured in the 1987/1988 season.

Despite their tremendous efforts in 2 years of training, no changes could be observed over the years either (except for body mass which increased significantly). Six out of the eight skaters, however, improved their best times in these years. When expressed in points calculated over the 500-m, 1500-m and 5000-m distances these performances improved from 123.5 points in the 1987/1988 season to 122.9 points in the 1989/1990 season (difference 0.49%). As a further step in the evaluation of these findings, we compared for individuals the changes in skating performance between these two seasons with the individual's changes in the power measurements and $\dot{V}O_{2max}$ values, since some improved their skating performances by more than 2% while others decreased by more than 2%. [It should be noted that a change of 2% in points corresponded with a change of approximately 5% in power (Ingen Schenau 1982).] These changes are presented in Table 3. However, no significant relationship could be found between the changes in performance and the changes in the test results.

Table 3. Changes in performance (points) and in tests of the individual male skaters between 1987/1988 and 2 years later (1989/1990)

Subject no.	Points	P_{peak}	$\bar{P}$ ($W \cdot kg^{-1}$)	$\bar{P}_{2.5}$	$\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)
1	+3.7	−1.2	−1.0	−0.4	−1.7
2	−2.3	−0.6	−0.1	−0.1	−5.1
3	−1.5	−0.6	−0.7	+0.1	+0.1
4	−0.4	+1.3	−1.0	−0.1	+0.6
5	−0.6	+0.6	−0.1	+0.2	+1.1
6	−2.2	0	−0.7	0	−2.2
7	+1.8	−0.3	−0.6	−0.7	+1.4
8	−2.9	+0.4	+0.2	−0.3	−1.1

Note that an improvement in performance means a decrease in points. For definitions see Table 2

The absence of shifts in the variables presented in Table 2 was in contrast to other longitudinal studies on young athletes. Rusko (1987) has reported a marked increase of $\dot{V}O_{2max}$ in young cross-country skiers. Comparable results have been reported for runners by Murase et al. (1981) and for athletes from various competitive sports by Paterson et al. (1987). Rusko (1987) has argued that this increase might be due to the fact that these athletes train progressively more and more every year. This, however, was not the case with the Dutch junior speed skaters. Despite their youth these skaters trained only slightly less than the senior's. This intense training might explain the results of this study. It seems likely that the effects of training in these skaters had already levelled off before the tests were performed. Evidence for this statement might be deduced from a comparison of the mean test results with corresponding values reported for elite senior skaters. With respect to $\dot{V}O_{2max}$, the junior skaters appear to have fallen completely within the range of values found for senior skaters (Ingen Schenau et al. 1983; Ingen Schenau and de Groot 1983a; Foster et al. 1990) and were higher than those found for Japanese senior skaters (Nemoto et al. 1988). For the sprint test we have found comparable values in senior male skaters (unpublished results) while the values of our junior men and women were significantly greater than those reported for American skaters (Foster et al. 1990). Obviously, the skaters had already reached the maximal levels which can be attained with this training programme for given genetic components (Fagard et al. 1991), the period of rest (or reduced training) being too short for a substantial decrease in their physical condition.

A challenge to sport sciences

The results of this study indicate a general problem in sport sciences in that the majority of studies of training and of predictors of performance are based on comparisons of groups of athletes with distinct differences in performance level or on correlations among groups which are much less homogenous than the groups tested in the present study. With those types of studies it has been shown for speed skating that various physiological parameters such as $\dot{V}O_{2max}$, $\overline{P}_{2.5}$ and especially $\overline{P}$ show strong correlations with performance (up to $r=0.85$; Geijsel et al. 1984; Foster et al. 1990). However, none of these parameters correlated with performance within the two homogenous groups of the present study. This does not mean that these parameters are less important in elite skaters but it is likely that, from a given level onwards (which should be judged as a prerequisite and which should be maintained), changes in performance depend on a broad accumulation of technical, physiological and psychological factors. Biomechanical analyses, however, have shown that even in homogenous groups of participants of international championships, a number of technical aspects can be distinguished which still correlate with performance (Ingen Schenau et al. 1985; Boer and Nilssen 1989; Koning et al. 1989). It is difficult, however, to translate such findings into programmes aimed at the improvement in performance of the skaters.

Since many coaches deal with rather homogenous groups of already highly-trained athletes, it is a challenge for sport scientists to find out what types of study might answer their questions with respect to the effects of their training programmes. It would seem likely that this would require a multi-disciplinary approach although a confirmed physiologist might argue that other physiological tests are available. As stated by Foster et al. (1990) such tests should meet the following criteria:

1. They should provide measurements which have significant correlations with performance
2. They must reflect seasonal progression with training

In addition to these two we would propose a third criterion:

3. They should provide measurements which allow a sound and unambiguous physiological interpretation and which can be translated into training.

Foster et al. (1989, 1990) have shown that in American speed skaters endurance time during cycling at a given load increases during the season while endurance time also appears to correlate with performance. Though this correlation was calculated for a rather heterogenous group of skaters (1500 m times between 1.53 min and 2.25 min) and is likely to be absent within more homogenous groups, this might point to a physiological phenomenon which has not received much attention in the speed skating literature: the accumulation and removal of muscle and blood lactate. Foster et al. (1990), however, did not find a seasonal shift in anaerobic threshold during cycling experiments which might indicate that much more specific (and more complicated) tests are necessary. Specific (skating) tests, however, are not possible in the dry land season, while during the ice season these tests are difficult to standardize due to changing conditions (even in indoor rinks the air density and ice friction vary considerably) while such tests do not provide reliable estimates for power production. Moreover, skating technique will also (markedly) influence such test results. Since Groot et al. (1985) have shown that, despite the use of the same muscle groups, cycling is not analogous to skating (large difference in instantaneous P_{peak} within the cycles), there seems to be the necessity to develop an ergometer which allows the mimicing of the much more explosive push off in skating

In conclusion, it can be stated that the well-known cycle ergometer tests which are widely used to measure aerobic and anaerobic power would not appear to be of use in evaluating seasonal progression in performance of homogenous groups of highly trained speed skaters.

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